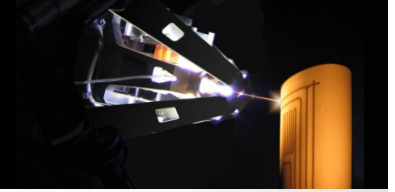


*Providing our customers with structurally integrated electronics  
for advanced sensing, communications, and signals intelligence.*



## Direct Write Sensors for Space and Probe Applications

**J.A. Brogan<sup>1</sup>, R.J. Greenlaw<sup>1</sup>, D.T. Arthur<sup>2,3</sup>, R.C. Anderson<sup>2</sup>, J.E. Andrade<sup>3</sup>**

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<sup>2</sup> Jet Propulsion Laboratory, Pasadena, CA

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11<sup>th</sup> International Planetary Probe Workshop, June 16-20, 2014

# Presentation Outline

- Company Overview
- Direct Write Printing Capabilities
- Direct Write Sensors/Instrumentation
  - ✧ Thermocouples
  - ✧ Heat Flux Gages
  - ✧ Recession Sensors
  - ✧ Heaters
  - ✧ Integrated Wiring
  - ✧ Antennas
- Summary

# About MesoScribe Technologies

- Founded in 2002, spin-off from Stony Brook University
  - ✧ DARPA MICE Program
- Provider of 3D printing services and products for aerospace, energy, and military markets
  - ✧ Conformal sensors, printed traces, and antennas
- Seeking manufacturing opportunities and strategic partners



Formerly located at the Long Island High Technology Incubator at SBU (LIHTI)

## **Corporate Office**

MesoScribe Technologies, Inc.  
7 Flowerfield, Suite 28  
St. James, NY 11780  
Tel: 631.686.5710

## **Manufacturing Center**

MesoScribe Technologies, Inc.  
5445 Oceanus Drive, Suite 108  
Huntington Beach, CA 92649  
Tel: 714.894.8400

# What is Direct Write?

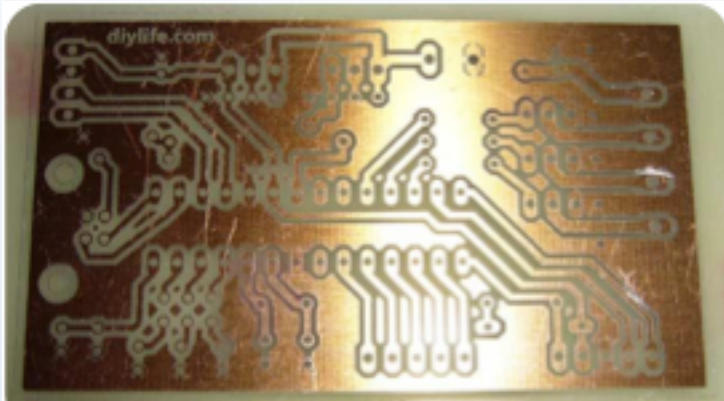
- A family of fabrication processes that allow maskless patterning of materials directly from a CAD file
- Also Referred to as Digital Printing of Materials
- Direct Write allows sensors, antennas, and integrated wiring on components or embedded within structures

## MesoPlasma™ Direct Write Processing



# Benefits of Direct Write Fabrication

- **Traditional Electronics –**  
Plate all surface with 1 material then remove unwanted material.



- ✧ Flat, stiff substrates (occasionally flexible),
- ✧ Limited materials, copper only
- ✧ Requires masking and hazardous etching materials

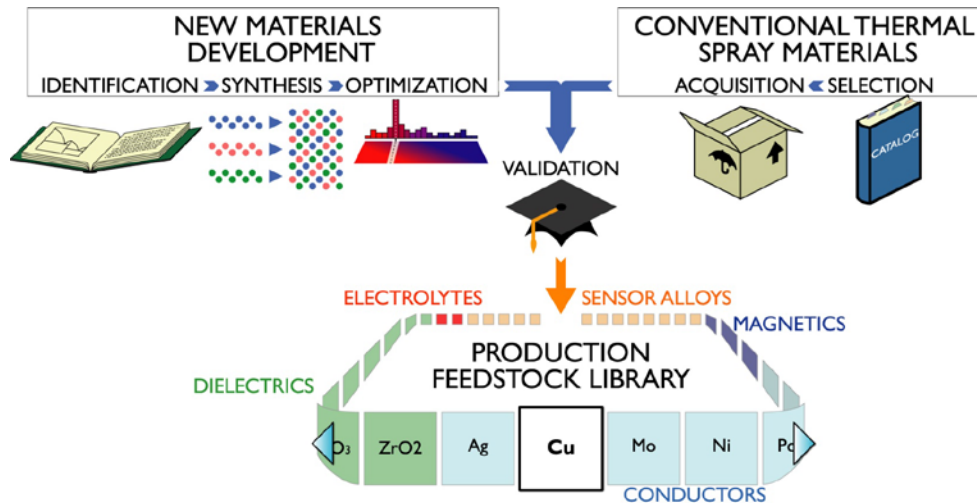
- **Direct-Write Electronics -**  
Deposit only the material needed where it is needed.



- ✧ Complex, curved parts of most any material
- ✧ Many material choices (metals, alloys, semiconductors, ceramics)
- ✧ No masking, no etching, and in many cases, no post processing needed

# Direct Write Fabrication- Capabilities

## Broad Feedstock Library



### Conductors

✓ Cu, Ni, Pt, Pd, Ag

### Sensor Alloys

✓ NiCr, NiAl, NiSi, NiCrSi, CuNi

✓ NiCrAlY, FeNi, PdAg

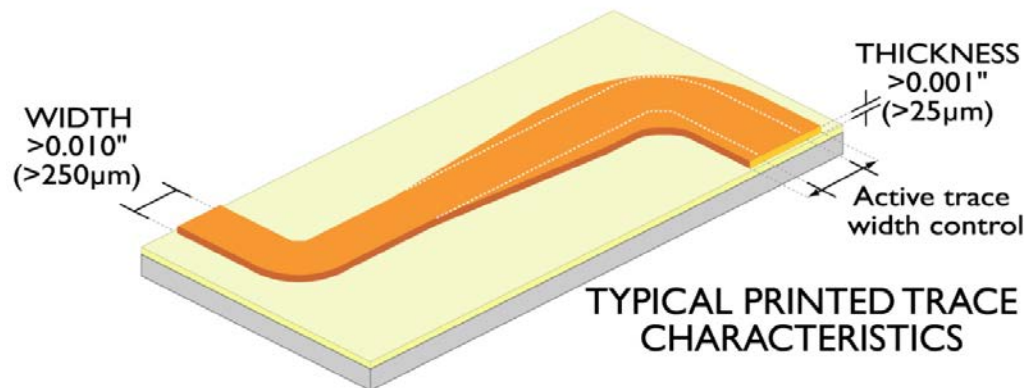
### Advanced Sensor Materials

✓ ITO and other ceramic TE oxides

### Dielectrics

✓ YSZ, MgAl<sub>2</sub>O<sub>4</sub>... proprietary matls

## Feature Sizes



### Dynamic feature control

✓ Trace geometry can be actively tailored for complex patterns

### Feature width

✓ Sensor traces ≥0.010" (≥250μm)

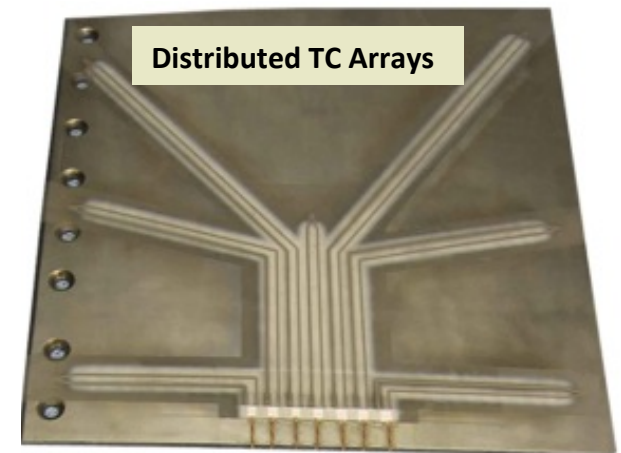
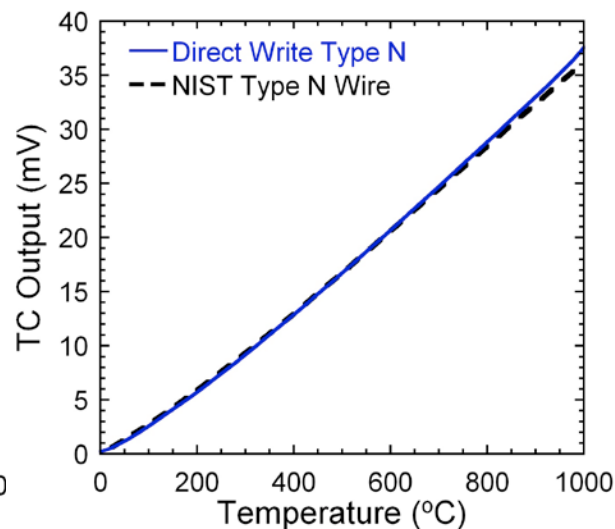
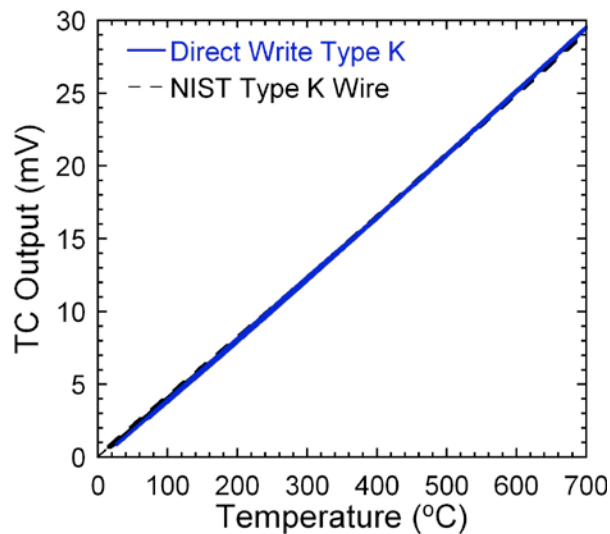
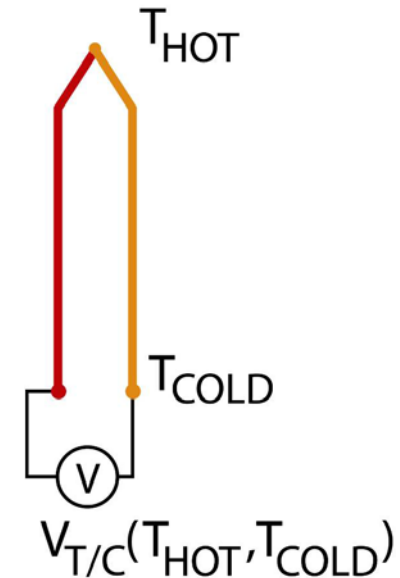
### Feature Thickness

✓ Sensor traces ~0.001" (≥25μm)



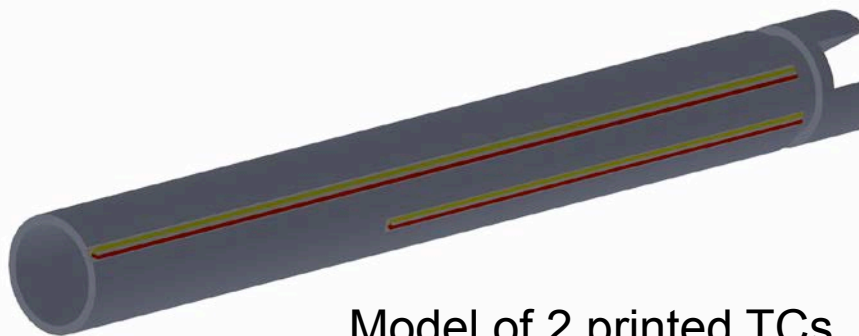
# Direct Write Thermocouples (TCs)

- Passive devices that provide measurements of **component temperature**
  - ✧ Standard NIST designations (Types T, E, K, N)
  - ✧ Precious metal (Pt-Pd) and ceramic oxide TCs for use at elevated temperatures, > 1500F
- Improved accuracy achieved through post heat-treatments above use temperature
  - ✧ Within 2% error is achievable

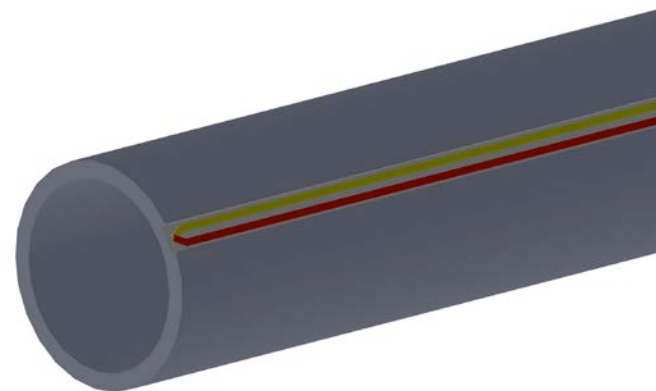


# 2020 Mars Rover Coring Bit

- Plan to instrument prototype HoneyBee Robotics 2020 coring bit with low profile thermocouples
- Aim is to understand thermal conditions likely to be experienced by rock core samples during the upcoming 2020 Mars Sample Return mission
- Will help establish drilling parameters
- Data will enable Caltech Computational Geomechanics to produce thermal models for JPL to make informed decisions about which science-driven constraints to impose on mission

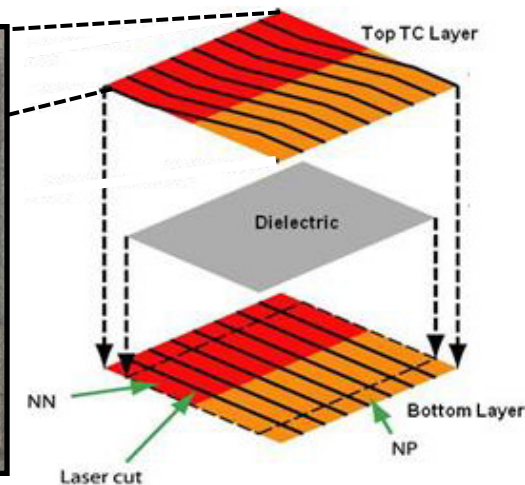
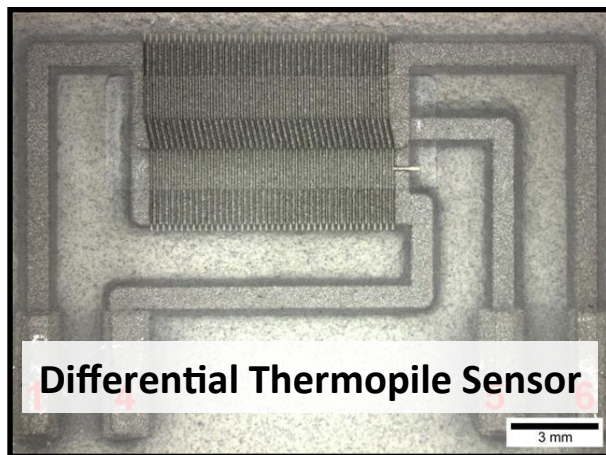


Model of 2 printed TCs





# Direct Write Heat Flux (HF) Sensors



Specifications
Max Operating Temp: 800°C
Responsivity: 400μV per W/cm <sup>2</sup>
Absorptivity: 0.94 (w/ emissivity coating)
Response Time: < 100ms (63.2%)
Sensor Size: 10x3mm (0.39"x0.12")

## ■ Benefits

- ✧ Low profile design
- ✧ No water cooling
- ✧ High temperature
- ✧ No adhesive/carrier limitations
- ✧ High sensitivity
- ✧ Custom sizes
- ✧ Printed onto part or provided as a stand alone sensor

## ■ Potential Space Applications

- ✧ In-situ monitoring of heat shield/TPS
- ✧ Monitoring of back-shell
- ✧ Instrumented calorimeter plugs for calibration of testing conditions (i.e. Arc-jet)

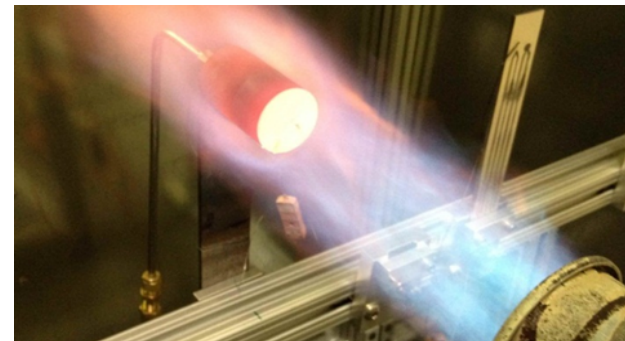
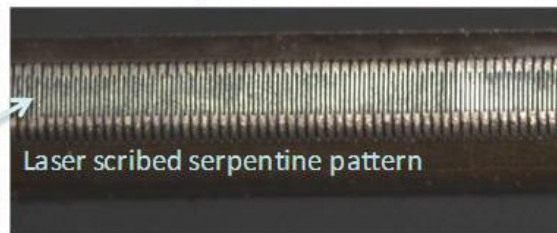


# Recession-Tolerant Sensors for Thermal Protection Systems

## TECHNOLOGY NEED

**In-Situ diagnostic tools are needed for ablative TPS flight systems to provide better correlation from modeling to actual performance.**

- Capability to print sensors onto heat shield materials
- Improved recession sensors using thermally activated ceramics
  - ✧ Higher sensing temperature than Kapton (1,000C demonstrated)
  - ✧ Improved repeatability, not subject to Kapton char variability
- New recession-tolerant thermocouples and heat flux gage designs

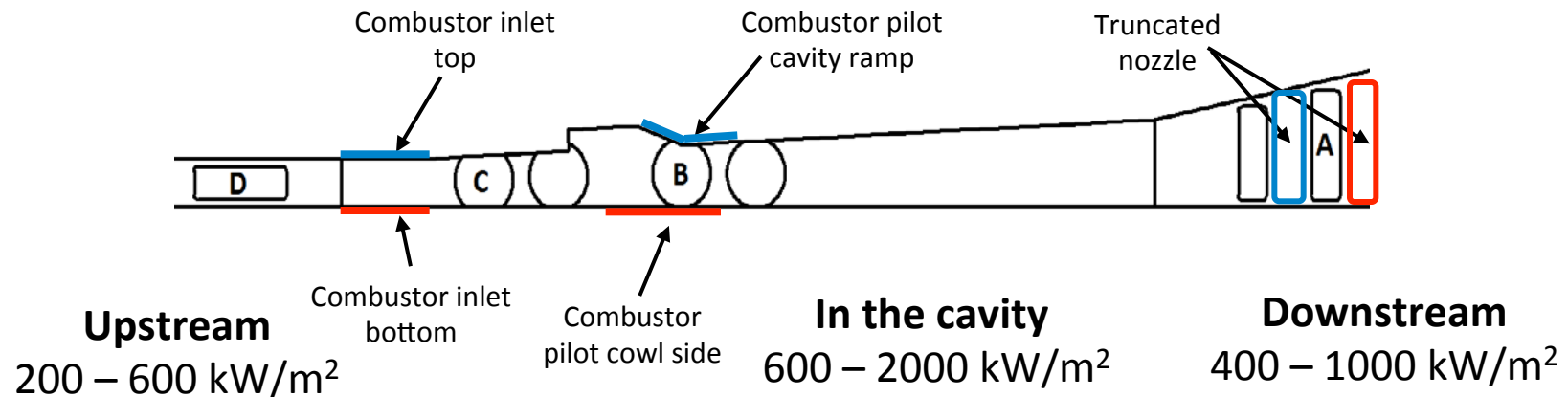
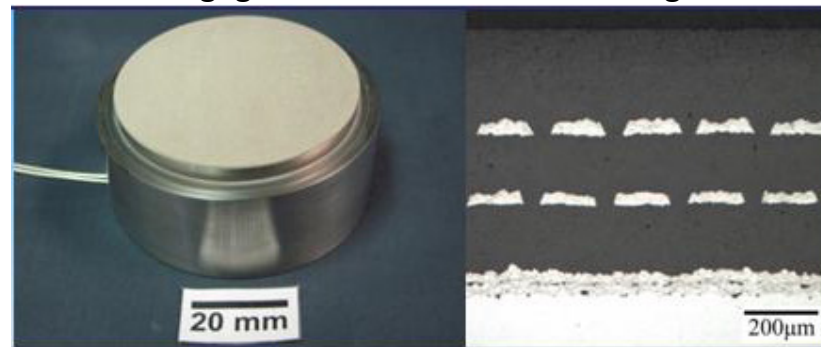


# Hypersonic Scramjet Instrumentation

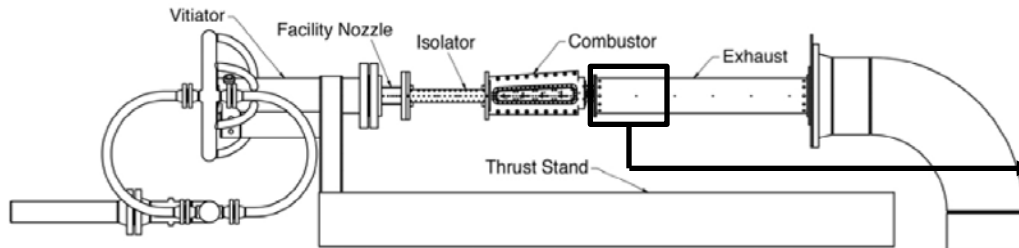
- Direct Write heat flux gages are used in hypersonic SCRAMJET engine development
  - ✧ Demonstrated at AFRL/WPAFB direct connect tunnel test
  - ✧ Mach 5 flow, 3,000°F combustor gas temperature
  - ✧ Fast response sensor, high temperature capable, no water cooling



Heat Flux gages embedded within coating



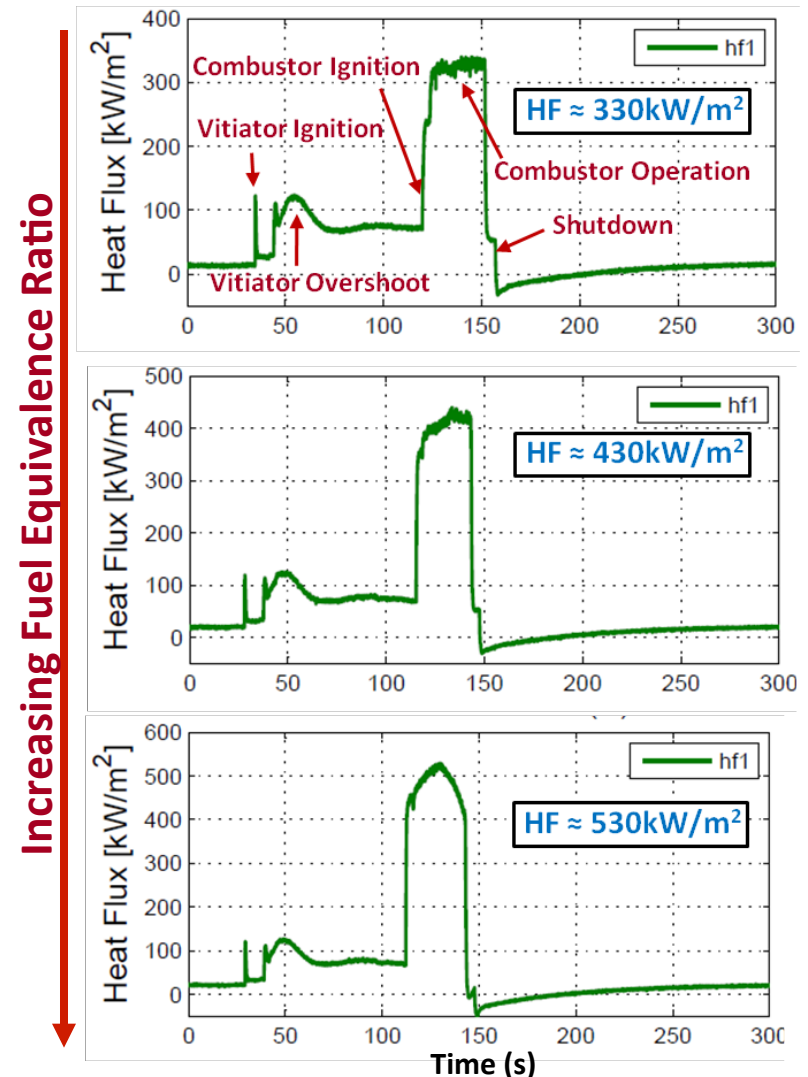
# Results: Down-stream of the Combustor



## Noteworthy Results

- ❑ Characteristic responses are mutually consistent and analogous to the sensors installed within the isolator and combustor
- ❑ Heat flux scales with the fuel equivalence ratio, as expected for down-stream locations
- ❑ Transient effects also apparent in Direct Write sensor responses
- ❑ Negative indicated heat flux upon cooling, which trends back to the pre-test value

## Sensor Response from Exhaust Nozzle





# Printed Heaters

## ■ Benefits

- ✧ High Heat Flux (up to  $500\text{W}/\text{cm}^2$  )
- ✧ High efficiency, low contact resistance
- ✧ High temperature (no adhesive/carrier limitations)
- ✧ High reliability (eliminates adhesive-related failures), reduces redundancy
- ✧ Ability to print directly to complex, conformal surfaces

## ■ Can be integrated with printed thermocouples for closed-loop control

## ■ Space Applications

- ✧ Satellite thermal control
- ✧ Fuel lines
- ✧ Ice-Detection and De-Icing
- ✧ Cryo-tanks



**Small Heater:**  
0.1" diameter x 0.25" long



**Large Heater 12" diameter**

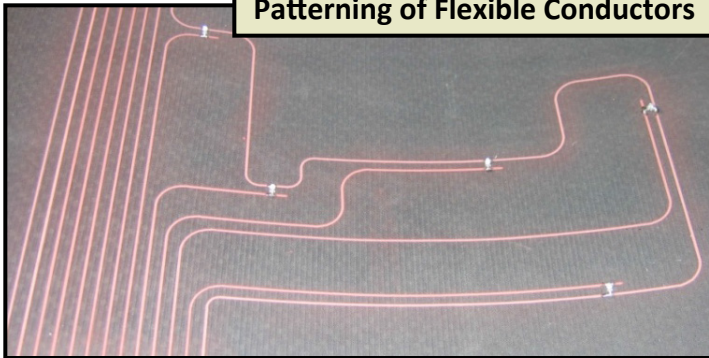
# Integrated Wiring



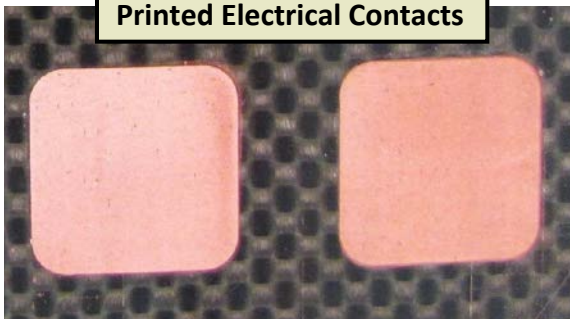
## DEMAND

Integrated conductors for signal routing to reduce installation costs and save space.

Patterning of Flexible Conductors

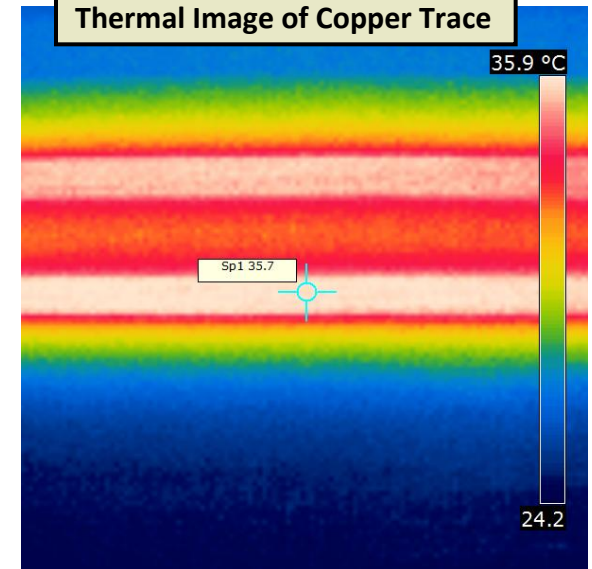


Printed Electrical Contacts



- Wires and connectors can be easily soldered to printed copper traces

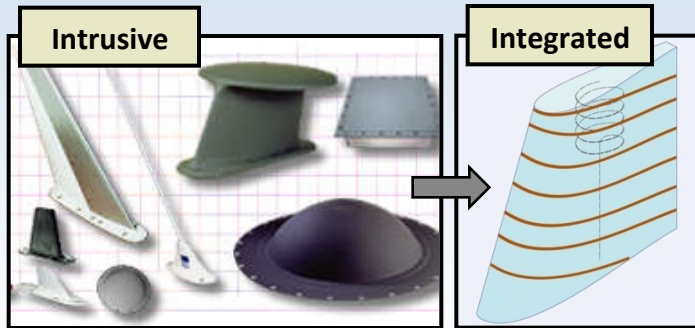
Thermal Image of Copper Trace



- 115 V, 11 amps
- ~10°C temperature rise



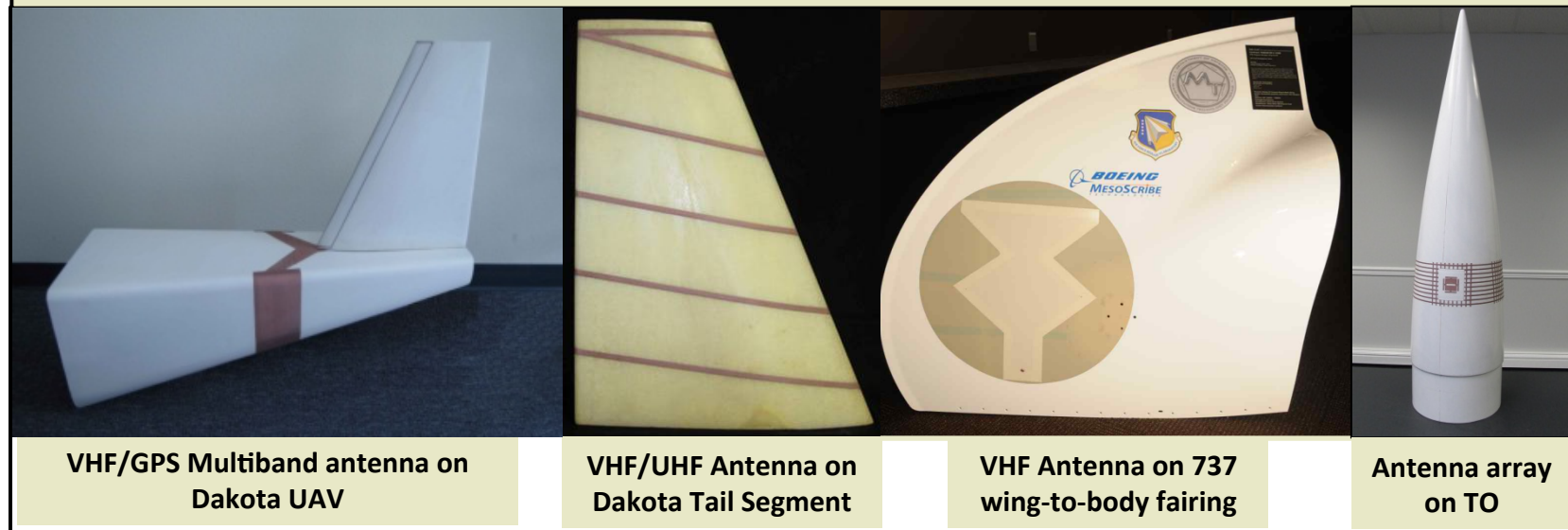
# Conformal and Integrated Antennas



## DEMAND

Replace bulky antennas that disrupt airflow with low-profile antenna structures that can be made conformal and/or structurally integrated within the air vehicle

## Direct Write Conformal Antennas



VHF/GPS Multiband antenna on Dakota UAV

VHF/UHF Antenna on Dakota Tail Segment

VHF Antenna on 737 wing-to-body fairing

Antenna array on TO

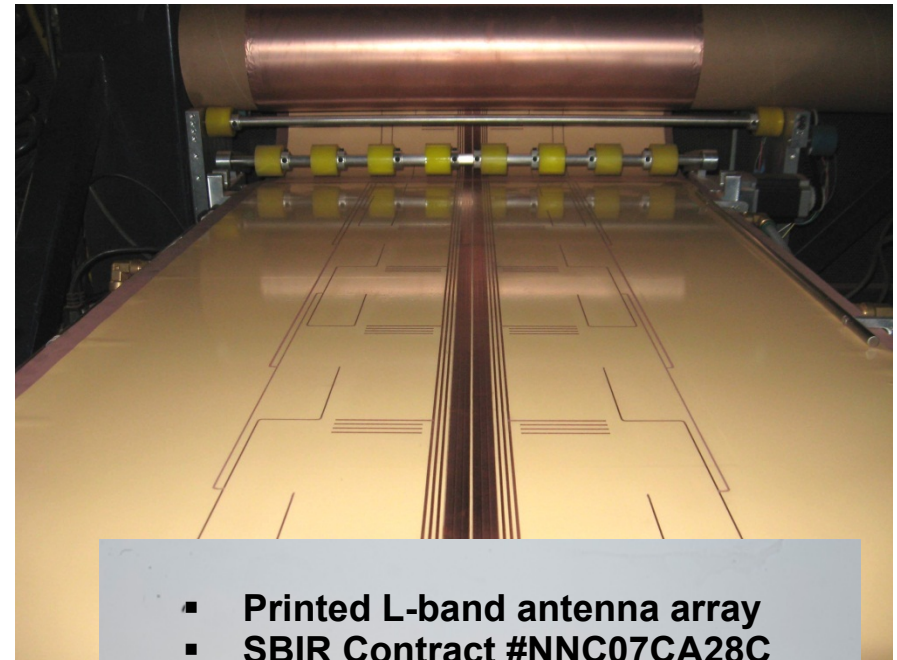
## ENABLE

Low-profile, conformal patterns for aerodynamic surfaces  
New antenna designs that offer low RCS and multi-band capabilities

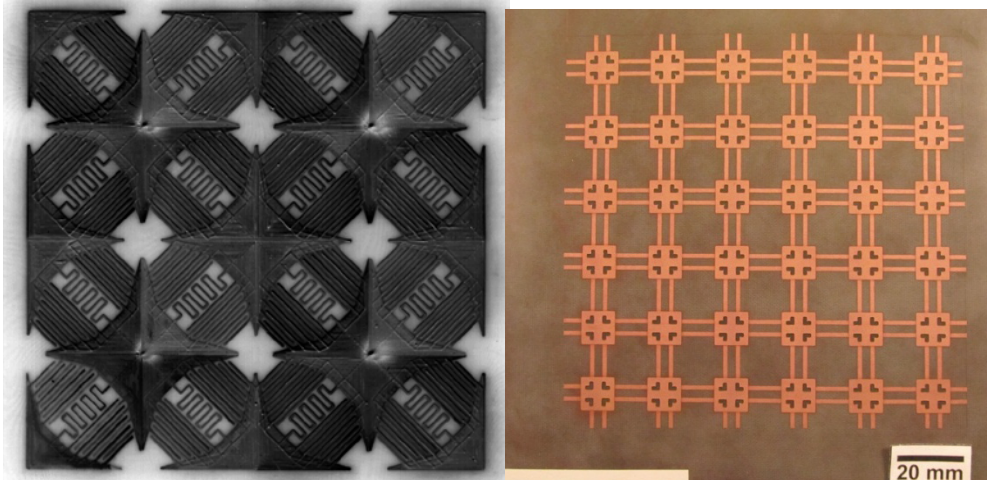
# Large Aperture, Flexible Antennas

## ROLL-TO-ROLL ANTENNA FABRICATION

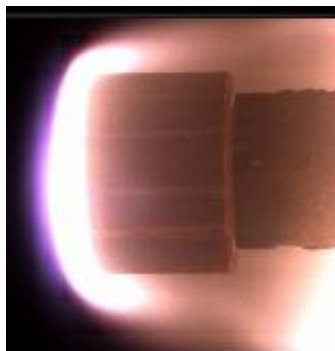
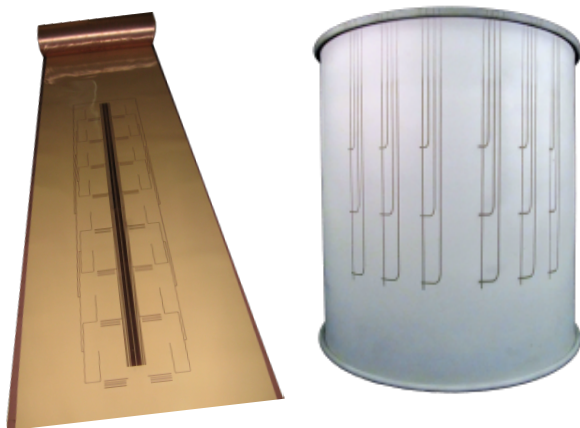
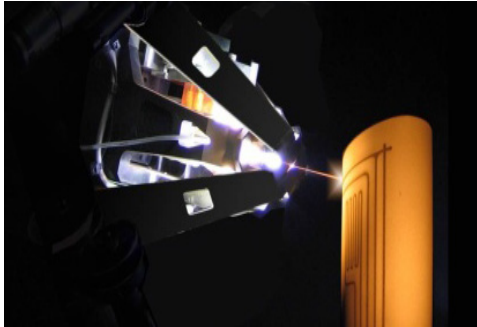
- ❑ MesoScribe has developed a **roll-to-roll deposition process** to fabricate antennas onto polymer laminates
  - ✓ Kapton™, LCP, Tedlar™
  - ✓ No length limitation
- ❑ Application for space-based L-band, unfurlable antennas, airships, etc.



## Frequency Selective Surfaces



# Summary



- Direct Write enables the integration of high performance sensors, antennas, and conductors directly on-the-part or embedded within the structure.
- Provides new diagnostic monitoring capabilities of components or structures in harsh environments.
- Seeking opportunities to instrument flight hardware for laboratory and mission environments.

For More Information, Contact:

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714-894-8400 x2#

[rgreenlaw@mesoscribe.com](mailto:rgreenlaw@mesoscribe.com)